THE JOURNAL OF PROSTHETIC DENTISTRY

RESEARCH AND EDUCATION

Comparisons of analog and digital methods to produce an accurate trial restoration

Yun-Shan Koh, BDS, MClinDent, M Pros,[a] Noland Naidoo, BChD, PDD, MDent,[b] and Haralampos Petridis, DDS, MS, Cert Prosthodont, PhD, FHEA[c]

ABSTRACT

Statement of problem. A trial restoration is an important diagnostic tool that can be fabricated through analog or digital pathways. Digital workflows may have improved accuracy, but this is yet to be demonstrated conclusively.

Purpose. The purpose of this in vitro study was to compare the dimensional accuracy of trial restorations produced by different analog (molded) and digital (milled and 3D printed) methods. Parameters studied included fabrication methods, Shore-A hardness of silicone putty indices, length of span, and labial tooth levels.

Material and methods. Digital additive trial restorations were designed on a single virtual cast from maxillary right to left lateral incisor teeth (4 teeth) and from maxillary right to left first premolar teeth (8 teeth). Both designs were identical on the 4 anterior teeth. Each digital trial restoration was 3-dimensionally (3D) printed to produce reference casts. The original cast was 3D printed to produce 44 replica casts. There were 8 experimental groups (4 analog and 4 digital) with 10 specimens each. For the analog groups, 20 silicone indices per reference cast were made: 10 from standard silicone putty (63 to 70 Shore-A hardness) and 10 from hard silicone putty (90 Shore-A hardness). The analog trial restorations were molded on replica casts with silicone indices and bis-acryl resin. The digital trial restorations were either milled or 3D printed and adapted onto replica casts. Each trial restoration was scanned and digitally superimposed onto respective scanned reference casts. Measurements were recorded at 3 levels: cervical, middle, and incisal. The independent samples Kruskal-Wallis, 2-sample Mann-Whitney, and Bonferroni tests were used to compare the distribution of accuracy among all groups (α=.05).

Results. The dimensional accuracy of the different trial restoration fabrication methods was comparable in terms of median values of trueness (how close the readings were to the reference), and no statistically significant difference was found among them (P>.05). When the dimensional accuracy in terms of precision (how close the readings were to each other) were analyzed, the hard putty groups demonstrated a statistically significant better outcome, whereas standard putty consistently showed the poorest result. The incisal level displayed the most significant deviation (P=.005) when all groups were compared. The incisal discrepancy values of the short-span standard putty trial restoration varied by as much as 0.84 mm in some specimens.

Conclusions. Milled and 3D printed trial restoration fabrication techniques showed dimensional accuracy comparable with that of the analog groups. However, the choice of silicone putty was shown to affect the dimensional accuracy of an analog molded trial restoration. A high Shore-A hardness silicone putty produced the best precision and should be used when fabricating an analog molded trial restoration. (J Prosthet Dent xxxx;xxx:xxx-xxx)

A trial restoration is a clinical replica of an analog or digital additive restorative design overlying the existing dentition. The trial restoration allows patients and clinicians to assess a proposed restorative outcome from an esthetic and functional perspective, enhancing predictability and serving as an excellent communication tool for the dentist, patient, and dental laboratory technician.[1–3] An accurate trial restoration provides the patient

Study completed in partial fulfillment for the Master of Clinical Dentistry in Prosthodontics degree at UCL Eastman Dental Institute, London, England, United Kingdom.
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.
[a]Graduate, Prosthodontic Unit, Department of Restorative Dentistry, UCL Eastman Dental Institute, London, England, UK.
[b]Clinical Lecturer, Prosthodontic Unit, Department of Restorative Dentistry, UCL Eastman Dental Institute, London, England, UK.
[c]Professor, Prosthodontic Unit, Department of Restorative Dentistry, UCL Eastman Dental Institute, London, England, UK.

Clinical Implications

A dimensionally accurate trial restoration can be fabricated with analog or digital workflows. However, to achieve a more dimensionally accurate outcome with an analog workflow, a silicone putty with a higher Shore-A hardness (≥90) should be used.

with a realistic preview of the intended outcome before proceeding with the proposed treatment.[2,4] Clinicians can also evaluate and communicate the need for procedures such as crown lengthening surgery or orthodontic or endodontic treatment.[5] Gingivectomies and osseous resection surgeries can be guided by the trial restoration, and this can significantly shorten the operating time.[6,7] In addition, a trial restoration can be used as a tooth reduction guide, allowing the clinician to gauge preparation dimensions to remove only the required tooth structure.[8–10] These clinical indications highlight the importance of having an accurate trial restoration.

Trial restorations can be fabricated through analog or digital pathways. The analog workflow involved a putty index made from a diagnostic waxing to directly mold the resin intraorally, whereas digital pathways involve either milling or 3-dimensionally (3D) printing the trial restoration shell to overlie the teeth. Whether current analog or digital techniques are more accurate is still unclear.

Cattoni et al[11] compared the accuracy of milled and molded trial restorations in vitro, reporting that the milled group had greater accuracy. However, the silicone putty used in that study had a Shore-A hardness of only 60, and 2 different restorative design versions were tested,[11] factors that could have had a confounding effect on the results.

Lo Giudice et al[12] compared milled and 3D printed trial restorations in vivo. Contradictory results were reported, with the milled trial restorations exhibiting a higher surface-to-surface matching percentage, but the printed trial restorations had better clinical fit. The discrepancy was attributed to the reductive algorithm of the surface matching software program. It was concluded that both digital methods presented a slight dimensional deviation from the initial design.[12] This study did not include an analog trial restoration group.

Moldovani et al[13] compared analog trial restorations produced from different types of silicone and resin materials. They reported that all trial restorations were larger than the restorative design, with the incisal third being the least accurate and that silicone putty with high Shore-A hardness when combined with dual-polymerized bis-acryl resin produced a more accurate trial restoration. They also suggested that future studies should compare the accuracy of milled and 3D printed trial restorations with their best analog trial restoration methods.[13]

Comparisons of the dimensional accuracy of trial restorations fabricated with different analog and digital techniques are sparse. Therefore, the aim of this study was to evaluate which trial restoration method produced the most accurate result. This study also evaluated the effect on dimensional accuracy of the Shore-A hardness of the silicone used, the length of span of the trial restoration, and the difference in accuracy at the cervical, middle, and incisal level of the tooth. The null hypotheses were that no difference in the dimensional accuracy of trial restorations would be found in fabrication methods when a harder silicone putty was used, with different span lengths, or at the cervical, middle, and incisal levels of the tooth.

MATERIAL AND METHODS

The parameters studied in this in vitro study included fabrication methods (analog, milled and printed), the Shore-A hardness of silicone putty indices (60 and 90 Shore-A hardness), the length of span of the trial restoration (short span from maxillary right to left lateral incisor or long span from maxillary right to left first premolar), and the difference in accuracy at the cervical, middle, and incisal level of the tooth. The 8 experimental groups were a conventional short-span trial restoration with standard putty (CLA), a conventional long-span trial restoration with standard putty (CLB), a conventional short-span trial restoration with hard putty (CA), a conventional long-span trial restoration with hard putty (CB), a milled short-span trial restoration (MA), a milled long-span trial restoration (MB), a printed short-span trial restoration (PA), and a printed long-span trial restoration (PB).

A pilot study was conducted of 8 groups with 1 specimen in each and used to calculate the sample size based on a 1-way analysis of variance with the 8 figures of means (0.11; 0.09; 0.12; 0.09; 0.09; 0.18; 0.05; 0.34), standard deviation (0.13), α=.05, and power of 80%. The calculated estimated sample size was 6 per group, but, to reduce the margin of error, a total of 10 specimens were used for each experimental group.

An impression of a fully dentate maxillary arch was made with a polyvinyl siloxane material (Aquasil Ultra+ Medium; Dentsply Sirona), and the produced stone cast was scanned with a laboratory scanner (CARES 7 Series; Institut Straumann AG) to create a standard tessellation language (STL) file. This STL file was imported into a computer-aided design (CAD) software program (DentalCAD 3.0 Galway; exocad GmbH) where a base added before it was saved as the virtual master cast (Fig. 1).

Digital additive trial restorations were created with the exocad program. Two 3D virtual wax pattern designs

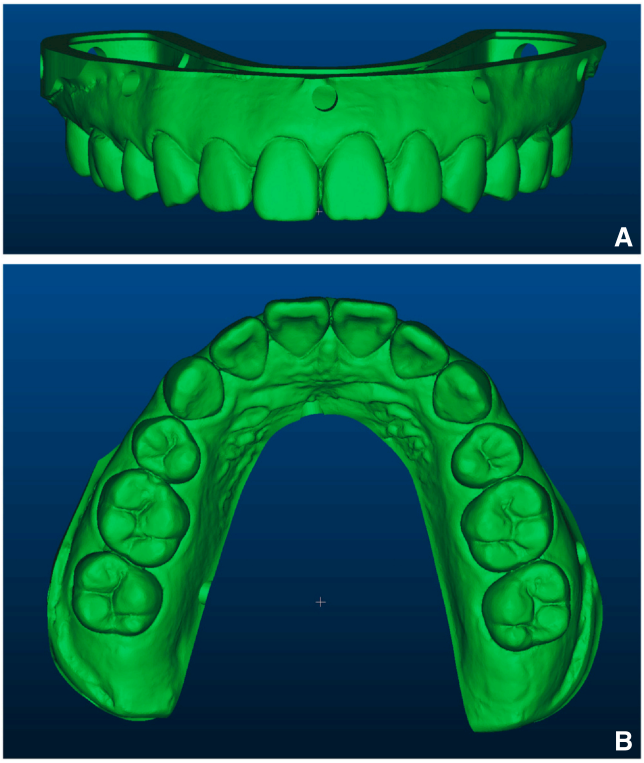

Figure 1. Standard tessellation language virtual master cast file. A, Frontal view. B, Occlusal view.

were produced (Fig. 2A, B). The first design included the maxillary right to left lateral incisor (4 teeth). The second design maintained the first design and extended the 3D virtual wax pattern to the maxillary first premolars on both sides (8 teeth). A linked trial restoration shell of

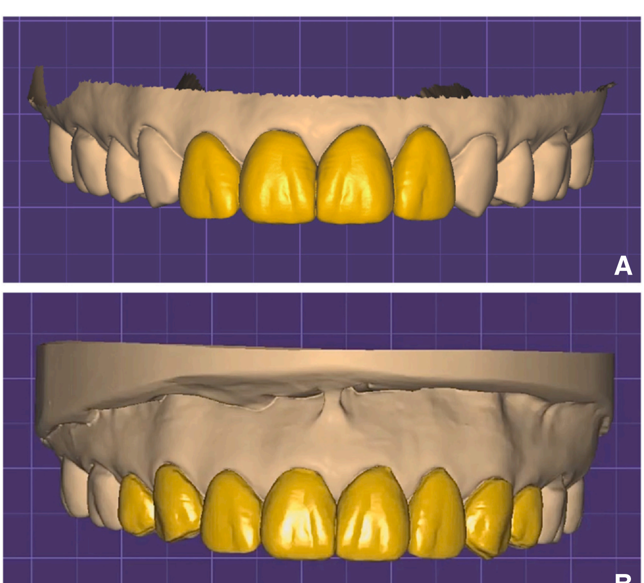

Figure 2. Three-dimensional virtual wax patterns. A, Short span. B, Long span.

each restorative design was created and saved for computer-aided manufacturing (CAM).

Each restorative design was merged separately with the underlying virtual master cast to create virtual reference casts (short- and long-span restorative design casts) which were later 3D printed and used to fabricate putty indices.

The STL files of the virtual casts were imported into a nesting software program (Netfabb 2022.0; Autodesk Inc) where the objects were oriented at 0 degrees to the build platform.[14] All casts were 3D printed with dimethacrylate acrylic resin (P Pro Master Model Grey; Institut Straumann AG) in a desktop DLP 3D printer (P Series Rapidshape P30^{+}; Institut Straumann AG). The 3D printed casts were cleaned with 99.9% isopropanol in an ultrasonic device (CARES P Wash; Institut Straumann AG) for 10 minutes, gently dried, and then light-activated polymerized for 5 minutes in a UV polymerization unit with an integrated vacuum (CARES P Cure Vacuum; Institut Straumann AG).

A total of 46 casts were 3D printed, which consisted of 2 reference casts (short and long-span trial restoration casts) and 44 replica casts. Ten replica casts were allocated to each conventional analog group for the resin trial restorations to be molded on, and 1 replica cast was allocated to each milled and 3D printed group (Fig. 3) for digital trial restoration shells to be placed on.

Ten silicone putty indices per reference cast were fabricated with both hard putty (Pala Lab Putty 90; Kulzer GmbH) and standard putty (Lab-Putty; Coltène), with a Shore-A hardness of 90 (hard putty) and 63 to 70 (standard putty). The putty was hand mixed according to the manufacturer's instruction and molded onto the reference casts. Each index extended to a tooth distal to the last abutment tooth, which ensured stable seating during the trial restoration fabrication. The second molars were left uncovered bilaterally as references for superimposing the STL files. Each index was polymerized for 4 minutes before removal. Overextended areas were trimmed, leaving a minimum of 3 mm between the cervical margin and the border of the index (Fig. 4). The indices were fabricated and used on the same day.

The fit of each index was assessed before loading it with a bis-acryl resin (Integrity; Dentsply Sirona). The loaded index was adapted onto a replica cast and left to polymerize for 5 minutes. The index was then retrieved, and the trial restoration was inspected for deficiencies (Fig. 5). Any defect resulted in the process being repeated. The trial restorations produced were stored until all specimens were ready to be scanned.

The 3D printed trial restoration shells were manufactured by importing the trial restoration shell STL files into the Netfabb program. These were oriented at 50 degrees to the build platform (Fig. 6). This ensured that resin support tags were only present on the palatal

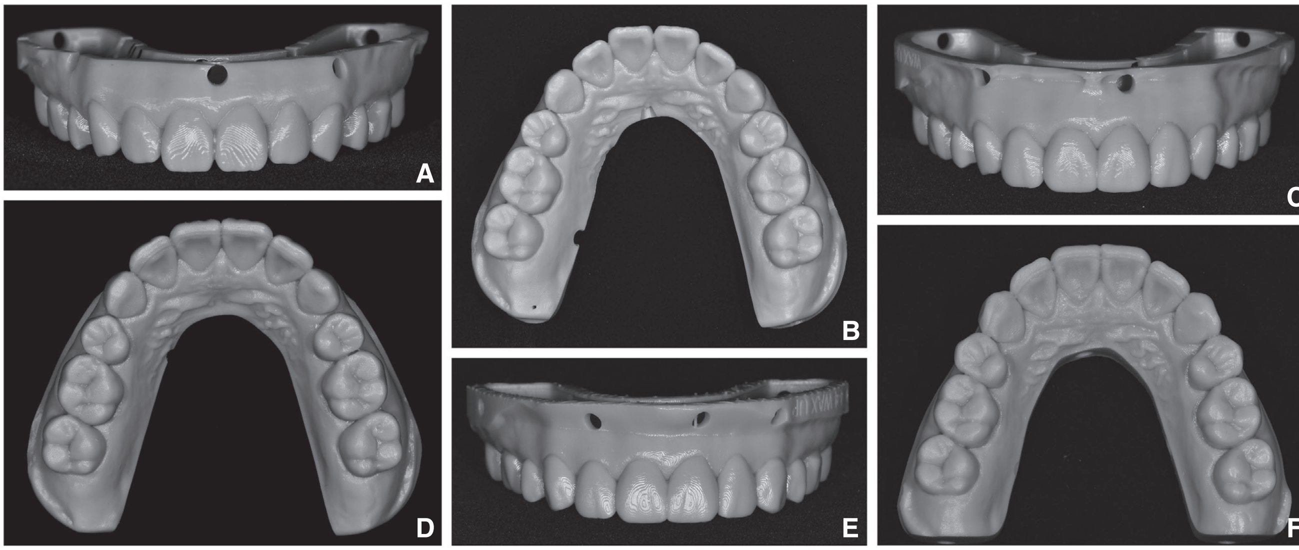

Figure 3. Three-dimensionally printed casts. A, Frontal view of replica cast. B, Occlusal view of replica cast. C, Frontal view of short span restorative design cast. D, Occlusal view of short span restorative design cast. E, Frontal view of long span restorative design cast. F, Occlusal view of long span restorative design cast.

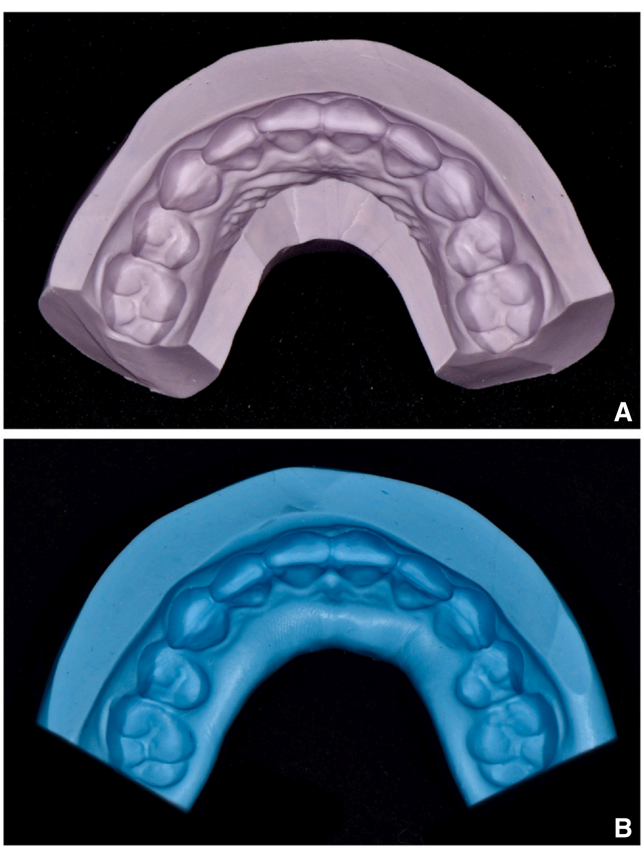

Figure 4. Long span silicone matrices A, Colténe Lab-Putty. B, Pala Lab Putty 90.

incisal overlap area, avoiding the intaglio or labial surfaces of the shell, which could have affected seating or measurement. Ten trial restoration shells of each design (Fig. 7) were 3D printed in a tooth-colored resin (GC Temp PRINT; GC Corp) with the Rapidshape P30$^+$ 3D printer. The 3D printed trial restorations were cleaned and subjected to light-activated polymerization using the same protocol as for the 3D printed casts. All trial restoration shells were 3D printed and used on the same day.

Ten short and long-span trial restoration shells were also milled (Fig. 8) in a 5-axis milling unit (DWX-53DC; Roland DGA Corp) from polymethyl methacrylate disks (PMMA Block; Huge Dental Material Co Ltd). These trial restoration shells were inspected for defects before adaptation onto the allocated replica cast (Fig. 8B, D).

All the completed trial restorations were scanned with the desktop laboratory scanner. The 3D printed reference casts were also scanned with the same cast scanner to allow for consistency during the comparison process.

A surface registration software program (CloudCompare version 2. X, 2022; GPL) was used to align the scanned trial restoration STL files to the reference cast STL files. This 3D point cloud processing software program was designed to handle triangular meshes and calibrated images. The imported meshes were aligned with the reference best-fit alignment. The cusp tips of the right and left second molars were used as fixed reference points for superimposition (Fig. 9). The computation of mesh-to-mesh distance was completed with a color scale and color indicated models (Fig. 9B, D). Point measurements were made at cervical, middle, and incisal locations along the long axis of each trial restoration tooth (Fig. 9C). The readings were recorded as positive deviation from the reference mesh.

The collected data were tabulated into separate tables in worksheets (Excel 2018; Microsoft Corp) for each experimental group and then later imported into a

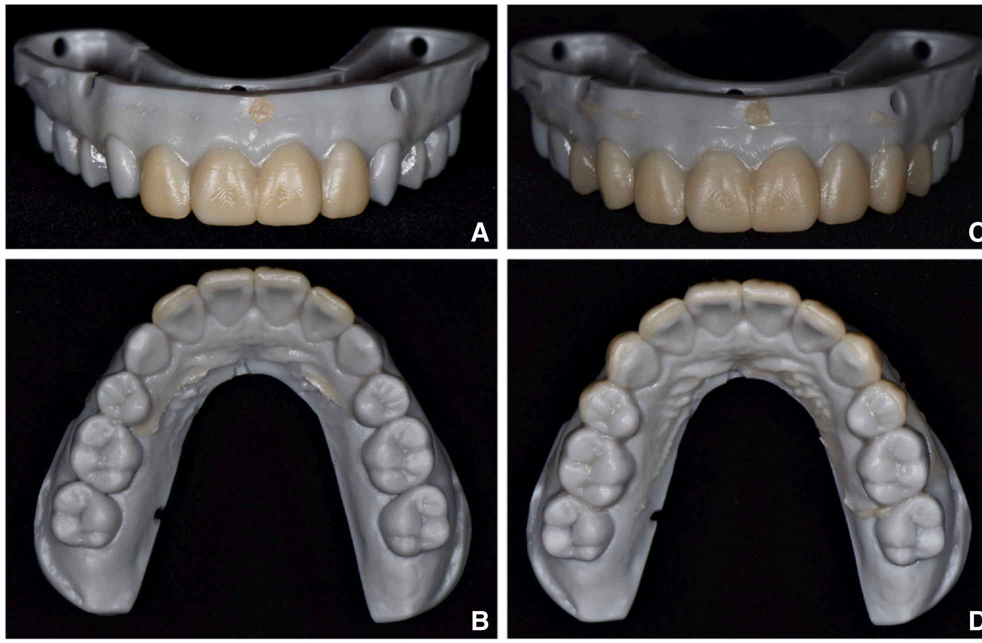

Figure 5. Analog trial restorations fabricated with Integrity and Pala Lab Putty 90. A, Frontal view of short span hard putty analog trial restoration. B, Occlusal view of short span hard putty analog trial restoration. C, Frontal view of long span hard putty analog trial restoration. D, Occlusal view of long span hard putty analog trial restoration.

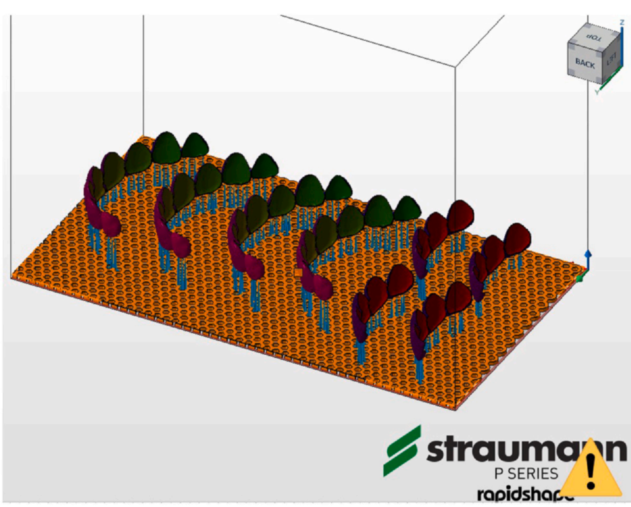

Figure 6. Trial restoration shells nested for prototyping at 50 degrees to build platform.

statistical software program (IBM SPSS Statistics for Windows, v28.0; IBM Corp) for statistical analysis. As the data were not normally distributed (Fig. 10), nonparametric tests were used. The hypotheses were tested using the Kruskal-Wallis test, 2-sample Mann-Whitney test, and a post hoc analysis with Bonferroni correction (α=.05).

Dimensional accuracy was evaluated in terms of trueness and precision. Trueness was defined as how close the trial restoration was to the trial restoration design. The smaller the deviation the greater the trueness. Precision was assessed according to how close the readings were to each other. Therefore, the resultant median values were interpreted for trueness, whereas precision was represented by range (minimum-maximum) and deviation across 3 levels.

RESULTS

The summarized data were analyzed and are presented in Table 1. Hard putty groups (CA and CB) displayed the best accuracy in terms of trueness (smallest median of 0.19 mm and 0.12 mm) and precision (smallest range of 0.21 mm and 0.19 mm). The 10 values of average deviations obtained from the 10 specimens in each group were used for statistical analysis. As the data were not normally distributed, the independent samples Kruskal-Wallis test was used, and the average dimensional discrepancies of trial restorations across all analog and digital methods were statistically similar (*P*=.174). The effect of Shore-A hardness on dimensional accuracy among the analog putty groups was analyzed with 2 pairs of comparisons. The resultant *P* values were.393 for CLA-CA and.218 for CLB-CB comparisons.

The effect of length of span on trial restoration accuracy was analyzed with 4 comparison pairs (CA-CB, CLA-CLB, MA-MB, PA-PB). The CA-CB comparison resulted in a *P* value of.043, which demonstrated that the CB (hard putty long-span) group was more dimensionally accurate. No significance was found for the CLA-CLB (*P*=.315), MA-MB (*P*=.684), and PA-PB (*P*=.853) group comparisons.

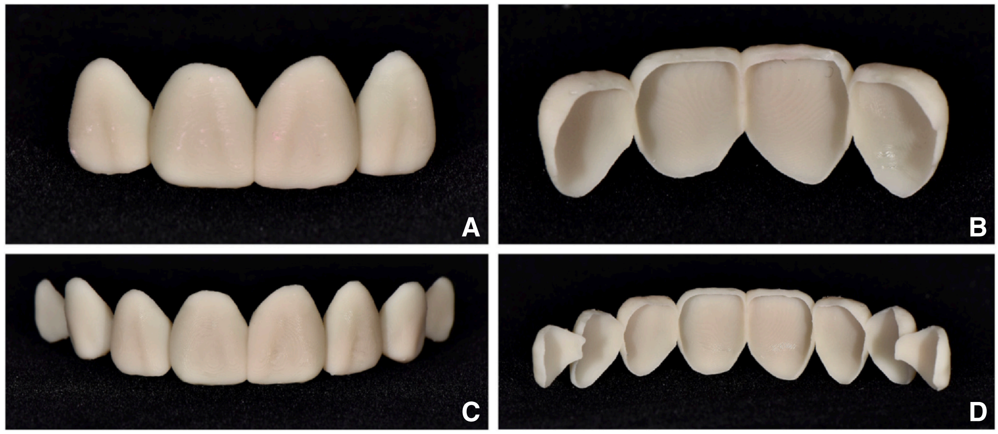

Figure 7. Three-dimensionally (3D) printed trial restoration shells. A, Frontal view of short span 3D printed trial restoration shell. B, Palatal view of short span 3D printed trial restoration shell. C, Frontal view of long span 3D printed trial restoration shell. D, Palatal view of long span 3D printed trial restoration shell.

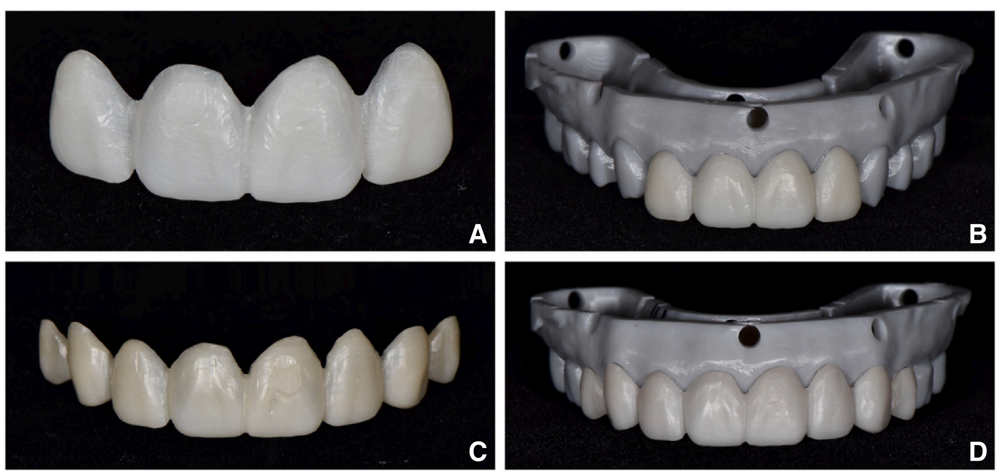

Figure 8. Milled trial restoration shells. A, Short span milled trial restoration shell. B, Short span milled trial restoration shell on replica cast. C, Long span milled trial restoration shell. D, Long span milled trial restoration shell on replica cast.

The accuracy of the trial restoration at the cervical, middle, and incisal level of the tooth was first evaluated in each experimental group. Data were assessed at 3 levels as shown in Table 1. The standard putty (*P*=.012), milled (*P*=.003), and printed (*P*=.040) comparisons resulted in significant differences across the 3 assessed labial tooth levels.The short-span hard putty group (CA) was the only group that did not result in a significant difference across the 3 levels (*P*=.636). The Bonferroni test subsequently showed that the standard putty (CLA) group had the poorest precision among all short-span groups evaluated.

The accuracy of the trial restoration was also evaluated comparing all 80 specimens at each level. The resultant *P* values were.102 for cervical,.046 for middle, and.005 for incisal, indicating that trial restorations were significantly less accurate at the middle and incisal levels. Subsequently, 28 pairwise comparisons were performed based on Bonferroni corrected *P* values at these levels. At the middle level, none of the comparisons were statistically significant (Table 2). At the incisal level, significant differences were found for the PB-CLA (*P*=.031) and CB-CLA (*P*=.037) pairs (Table 3). Higher trueness was found in the CB (hard putty long-span) group with the median of 0.12 mm, followed by the PB group (0.13 mm). The poorest trueness with the biggest median (0.41 mm) was found in the CLA (standard putty short-span) group.

DISCUSSION

The null hypothesis that no difference in the dimensional accuracy of trial restorations would be found among all fabrication methods was not rejected as statistical tests did not show any significant difference in the median values (trueness) when all techniques were collectively compared and when the labial thirds were

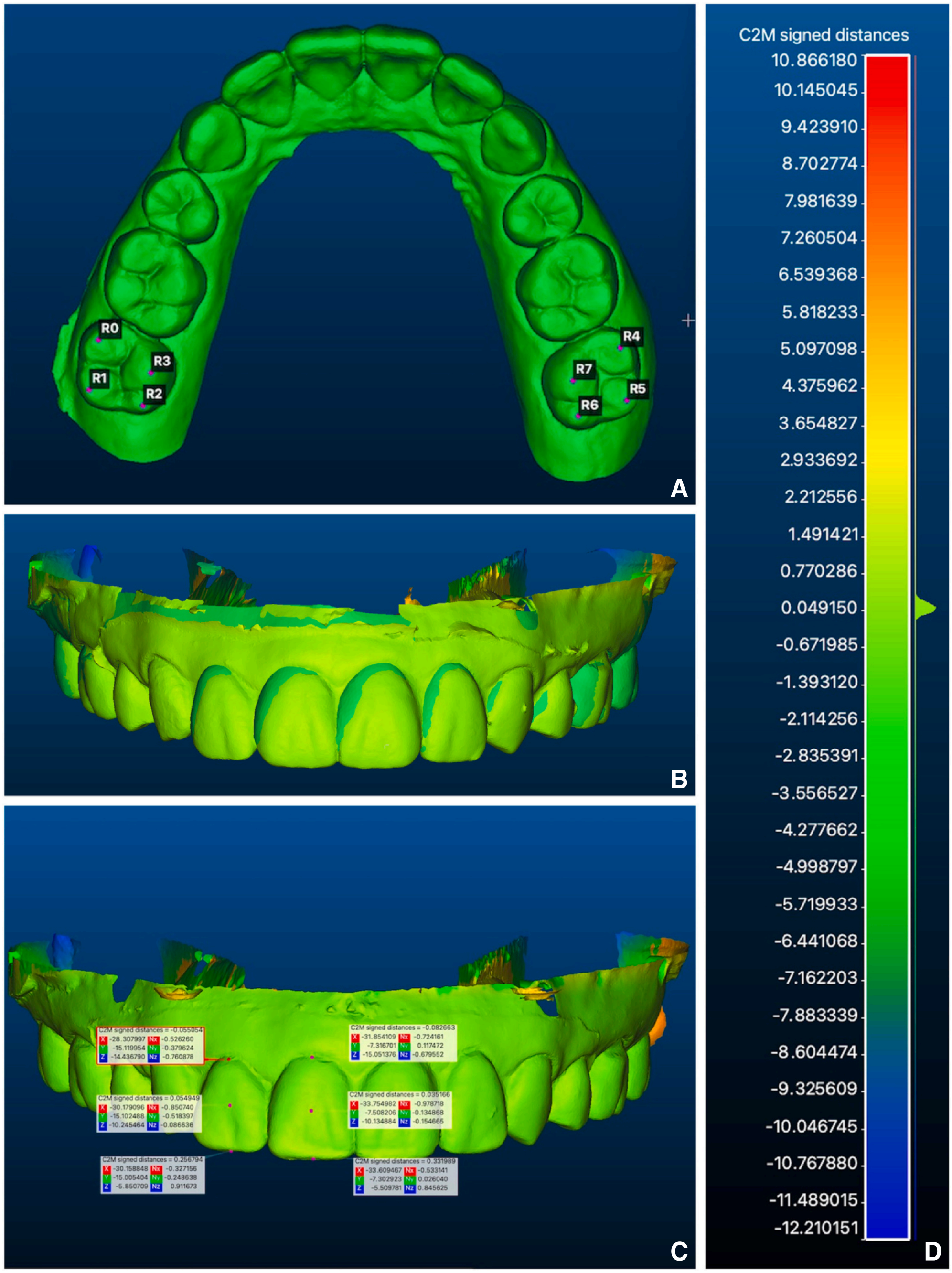

Figure 9. A, Cuspal tips used for fixed reference points. B, Mesh to mesh alignment of 2 loaded files. C, Cervical, middle, and incisal measurements of 2 aligned mesh files. D, Color scale with respective measurements.

not considered separately. However, when accuracy was evaluated at 3 levels, a high Shore-A hardness silicone consistently demonstrated a significantly greater precision and trueness compared with the other evaluated techniques. In contrast, the standard hardness silicone used for short-span trial restorations produced the poorest precision among 3 labial measurements, indicating that silicone with reduced stiffness is prone to plastic deformation when subjected to pressure during the fabrication of trial restorations. The more rigid hard putty, however, had less distortion or flexing, especially when retrieving it from the trial restoration cast during matrix fabrication process or when repositioning the index onto replica casts after loading the bis-acryl resin.

The null hypothesis that no difference would be found in the dimensional accuracy with different span lengths was only partially rejected because of significance found among the CA-CB comparison. The effect of the length of span was shown to influence the hard putty (CA-CB) groups only, where CB was significantly more accurate (P=.043) than CA.

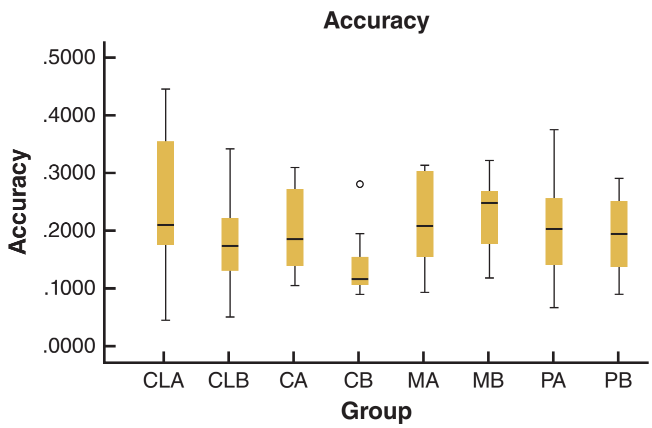

Figure 10. Overall accuracy distribution across all experimental groups (conventional long span trial restoration with hard putty (CB); conventional long span trial restoration with standard putty (CLB); conventional short span trial restoration with hard putty (CA,; conventional short span trial restoration with standard putty (CLA); milled long span trial restoration (MB); milled short span trial restoration (MA); printed long span trial restoration (PB); printed short span trial restoration (PA). *Black line* in each box represented median.

The hard putty groups demonstrated the smallest median (higher trueness) among all groups and performed well when being used for a long span, and the difference was statistically significant when compared with the short span. The greater accuracy was likely due to greater support that can be derived from a larger surface area in a long-span trial restoration.

The null hypothesis that no difference in the dimensional accuracy of trial restorations would be found at the cervical, middle, and incisal levels of the tooth was partially rejected because the dimensional accuracy of the trial restorations was found to be statistically less accurate at the incisal level across all groups, consistent with previous studies.[11,13] When the standard putty was used in this study for a short-span trial restoration, incisal readings differed by 0.84 mm. The high error accumulation at the incisal level can be attributed to the variation in applied pressure and susceptibility of silicone matrices to deformation when compressed and seated during resin hardening. The most accurate trial restoration for the incisal level was the hard putty silicone in the long-span group, attributed to its high stiffness and ability to retain its shape under pressure.

The digital trial restoration fabrication techniques showed comparable dimensional accuracy with the analog groups. The only significant difference was found among the long-span printed trial restoration (PB) and short-span standard silicone trial restoration (CLA) at the incisal level. This finding was consistent with that of other studies, which reported that digitally produced trial restorations had better clinical fit and improved accuracy compared with analog molded trial restorations.[11,12]

In addition to the predictability and reproducibility of digitally produced trial restorations, other advantages include the lack of excess material to remove intraorally, less concern over undercut engagement at the evaluation stage, improved patient comfort, and a shorter

Table 1. Summary data of experimental groups: conventional long-span trial restoration with hard putty (CB); conventional long-span trial restoration with standard putty (CLB); conventional short-span trial restoration with hard putty (CA); conventional short-span trial restoration with standard putty (CLA); milled long-span trial restoration (MB); milled short-span trial restoration (MA); printed long-span trial restoration (PB); printed short-span trial restoration (PA)

Groups	Levels	Min (mm) per Level	Min (mm) per Group	Median (mm) per Level	Median (mm) per Group	Max (mm) per Level	Max (mm) per Group	Range (mm) per Level	Range (mm) per Group
CLA	Cervical	0.05	0.05	0.13	0.21	0.42	0.45	0.37	0.40
	Middle	0.03		0.11		0.47		0.44	
	Incisal	0.04		0.41		0.88		0.84	
CLB	Cervical	0.04	0.05	0.11	0.17	0.39	0.34	0.36	0.29
	Middle	0.06		0.11		0.21		0.15	
	Incisal	0.03		0.3		0.49		0.46	
CA	Cervical	0.07	0.11	0.15	0.19	0.43	0.31	0.37	0.21
	Middle	0.08		0.22		0.38		0.29	
	Incisal	0.09		0.16		0.35		0.26	
CB	Cervical	0.05	0.09	0.12	0.12	0.27	0.28	0.22	0.19
	Middle	0.06		0.1		0.23		0.17	
	Incisal	0.06		0.12		0.52		0.46	
MA	Cervical	0.03	0.09	0.11	0.21	0.16	0.31	0.13	0.22
	Middle	0.05		0.23		0.34		0.29	
	Incisal	0.14		0.29		0.58		0.44	
MB	Cervical	0.11	0.12	0.17	0.25	0.32	0.32	0.21	0.20
	Middle	0.10		0.24		0.31		0.21	
	Incisal	0.10		0.26		0.52		0.42	
PA	Cervical	0.02	0.07	0.12	0.20	0.27	0.38	0.25	0.31
	Middle	0.04		0.21		0.35		0.31	
	Incisal	0.05		0.34		0.71		0.66	
PB	Cervical	0.08	0.09	0.18	0.20	0.39	0.29	0.31	0.20
	Middle	0.04		0.21		0.36		0.32	
	Incisal	0.07		0.13		0.27		0.21	

Table 2. Pairwise comparisons for dimensional discrepancies at middle level among experimental groups: conventional long-span trial restoration with hard putty (CB); conventional long-span trial restoration with standard putty (CLB); conventional short-span trial restoration with hard putty (CA); conventional short-span trial restoration with standard putty (CLA); milled long-span trial restoration (MB); milled short-span trial restoration (MA); printed long-span trial restoration (PB); printed short-span trial restoration (PA)

Group to Group	Test Statistic	Standard Error	Standard Test Statistic	Sig.	P[a]
CLB-CB	-1.150	10.392	-.111	.912	>.999
CLB-CLA	7.650	10.392	.736	.462	>.999
CLB-PA	-13.750	10.392	-1.323	.186	>.999
CLB-MA	-18.050	10.392	-1.737	.082	>.999
CLB-PB	-24.100	10.392	2.319	0.20	.571
CLB-MB	-25.050	10.392	2.411	.016	.446
CLB-CA	-25.450	10.392	-2.449	.014	.401
CLB-CLA	6.500	10.392	.625	.532	>.999
CB-PA	-12.600	10.392	-1.213	.225	>.999
CB-MA	-16.900	10.392	1.626	.104	>.999
CB-PB	-22.950	10.392	2.208	.027	.762
CB-MB	-23.900	10.392	-2.300	.021	.601
CB-CA	24.300	10.392	2.338	.019	.542
CLA-PA	-6.100	10.392	-.587	.557	>.999
CLA-MA	-10.400	10.392	-1.001	.317	>.999
CLA-PB	-16.450	10.392	-1.583	.113	>.999
CLA-MB	-17.400	10.392	-1.674	.094	>.999
CLA-CA	-17.800	10.392	-1.713	.087	>.999
PA-MA	4.300	10.392	.414	.679	>.999
PA-PB	-10.350	10.392	-.996	.319	>.999
PA-MB	11.300	10.392	1.087	.277	>.999
PA-CA	11.700	10.392	1.126	.260	>.999
MA-PB	-6.050	10.392	.582	.560	>.999
MA-MB	-7.000	10.392	.674	.501	>.999
MA-CA	7.400	10.392	.712	.476	>.999
PB-MB	.950	10.392	.091	.927	>.999
PB-CA	1.350	10.392	.130	.897	>.999
MB-CA	.400	10.392	.038	.969	>.999

Each row tests null hypothesis that distributions of compared groups same.

Asymptotic significances (2-sided tests) displayed (α=.05).

[a] *P* values adjusted by Bonferroni correction for multiple tests.

Table 3. Pairwise comparisons for dimensional discrepancies at incisal level among experimental groups: conventional long-span trial restoration with hard putty (CB); conventional long-span trial restoration with standard putty (CLB); conventional short-span trial restoration with hard putty (CA); conventional short-span trial restoration with standard putty (CLA); milled long-span trial restoration (MB); milled short-span trial restoration (MA); printed long-span trial restoration (PB); printed short-span trial restoration (PA)

Group to Group	Test Statistic	Standard Error	Standard Test Statistic	P	Adj P[a]
PB-CB	.550	10.392	.053	.958	>.999
PB-CA	6.800	10.392	.654	.513	>.999
PB-CLB	19.750	10.392	1.901	.057	>.999
PB-MB	21.850	10.392	2.130	.035	.994
PB-PA	22.650	10.392	2.180	.029	.820
PB-MA	26.900	10.392	2.589	.010	.270
PB-CLA	33.900	10.392	3.262	.001	.031
CB-CA	6.250	10.392	.601	.548	>.999
CB-CLB	19.200	10.392	1.848	.065	>.999
CB-MB	-21.300	10.392	2.050	.040	>.999
CB-PA	-22.100	10.392	-2.127	.033	.936
CB-MA	-6.350	10.392	-2.536	.011	.314
CB-CLA	33.350	10.392	3.209	.001	.037
CA-CLB	12.950	10.392	1.246	.213	>.999
CA-MB	-15.050	10.392	-1.448	.148	>.999
CA-PA	-15.850	10.392	-1.525	.127	>.999
CA-MA	-20.100	10.392	-1.934	.053	>.999
CA-CLA	27.100	10.392	2.608	.009	.255
CLB-MB	-2.100	10.392	-202	.840	>.999
CLB-PA	-2.900	10.392	-.279	.780	>.999
CLB-MA	-7.150	10.392	-.688	.491	>.999
CLB-CLA	14.150	10.392	1.362	.173	>.999
MB-PA	-.800	10.392	-.077	.939	>.999
MB-MA	5.050	10.392	.486	.627	>.999
MB-CLA	12.050	10.392	1.160	.246	>.999
PA-MA	4.250	10.392	.409	.683	>.999
PA-CLA	11.250	10.392	1.083	.279	>.999
MA-CLA	7.000	10.392	.674	.501	>.999

Each row tests null hypothesis that distributions of compared groups same.

Asymptotic significances (2-sided tests) displayed (α=.05).

[a] *P* values adjusted by Bonferroni correction for multiple tests.

clinical time required for trial restoration insertion. Disadvantages include the higher initial cost and laboratory fees, minimum thickness requirement for CAM produced trial restorations, and seating concerns in teeth with multiple undercuts. The analog trial restoration fabrication technique remains widely used for reasons that include practitioner familiarity, lower cost, ease of handling, and its versatility in most clinical scenarios.

Limitations of the study included the use of a single operator. The results therefore do not account for interoperator variability, which may introduce bias and could impact the reproducibility of the results. To enhance the reliability and validity of future research on this subject, multiple operators should participate in the data collection which may minimize biases and simulate clinical practice conditions. Other limitations included directly extrapolating the findings of in vitro studies and applying these to clinical practice. Therefore future research should consider an in vivo study design and perhaps compare the findings between the clinical and laboratory studies.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. Digital and analog methods for trial restoration fabrication produced comparable results.
2. The analog molded trial restorations were found to be a favorable fabrication method, but the choice of silicone used for the putty index can affect the dimensional accuracy of the trial restoration. A high Shore-A hardness silicone produced a trial restoration with better precision amongst all the short-span groups.
3. Improved accuracy at the incisal level was also found when a hard silicone putty index was used to fabricate a long-span trial restoration, followed by the long-span printed trial restoration.
4. The most inaccurate trial restoration was produced when standard silicone putty was used to fabricate a short-span trial restoration. Therefore, a high Shore-A hardness silicone putty (≥90) should be preferred

when producing an analog trial restoration to achieve a more dimensionally accurate outcome.

REFERENCES

1. Reshad M, Cascione D, Magne P. Diagnostic mock-ups as an objective tool for predictable outcomes with porcelain laminate veneers in esthetically demanding patients: A clinical report. *J Prosthet Dent*. 2008;99:333–339.
2. Gurrea J, Bruguera A. Wax-up and mock-up. A guide for anterior periodontal and restorative treatments. *Int J Esthet Dent*. 2014;9:146–162.
3. Garcia PP, da Costa RG, Calgaro M, et al. Digital smile design and mock-up technique for esthetic treatment planning with porcelain laminate veneers. *J Conserv Dent*. 2018;21:455–458.
4. Magne P, Magne M, Belser U. The diagnostic template: A key element to the comprehensive esthetic treatment concept. *Int J Periodontics Restorative Dent*. 1996;16:560–569.
5. Simon H, Magne P. Clinically based diagnostic wax-up for optimal esthetics: The diagnostic mock-up. *J Calif Dent Assoc*. 2008;36:355–362.
6. Jurado CA, Parachuru V, Villalobos Tinoco J, et al. Diagnostic mock-up as a surgical reduction guide for crown lengthening: Technique description and case report. *Medicina (Kaunas)*. 2022;58:1360.
7. Malik K, Tabiat-Pour S. The use of a diagnostic wax set-up in aesthetic cases involving crown lengthening–A case report. *Dent Update*. 2010;37(303-4):306–307.
8. Gürel G. Porcelain laminate veneers: Minimal tooth preparation by design. *Dent Clin North Am*. 2007;5:419–431.
9. Gurel G, Morimoto S, Calamita MA, Coachman C, Sesma N. Clinical performance of porcelain laminate veneers: Outcomes of the aesthetic pre-evaluative temporary (APT) technique. *Int J Periodontics Restorative Dent*. 2012;32:625–635.
10. Magne P, Belser UC. Novel porcelain laminate preparation approach driven by a diagnostic mock-up. *J Esthet Restor Dent*. 2004;16:7–16.
11. Cattoni F, Tete G, Calloni AM, Manazza F, Gastaldi G, Cappare P. Milled versus moulded mock-ups based on the superimposition of 3D meshes from digital oral impressions: A comparative in vitro study in the aesthetic area. *BMC Oral Health*. 2019;19:230.
12. Lo Giudice A, Ortensi L, Farronato M, Lucchese A, Lo Castro E, Isola G. The step further smile virtual planning: milled versus prototyped mock-ups for the evaluation of the designed smile characteristics. *BMC Oral Health*. 2020;20:165.
13. Moldovani D, Diamantopoulou S, Edelhoff D, Papazoglou E. Accuracy of indirect veneer mock-up in comparison to diagnostic wax-up. *Int J Prosthodont*. 2023;36:443–450.
14. Ko J, Bloomstein RD, Briss D, et al. Effect of build angle and layer height on the accuracy of 3-dimensional printed models. *Am J Orthod Dentofacial Orthop*. 2021;160:451–458.

Corresponding author:
Dr Noland Naidoo
Department of Restorative Dentistry
UCL Eastman Dental Institute
21 University Road
Rockefeller Building
London, England WC1E 6DE
UK
Email: n.naidoo@ucl.ac.uk

CRediT authorship contribution statement

Yun-Shan Koh: Conceptualization, Methodology, Investigation, Data Curation, Writing – original draft**. Noland Naidoo:** Writing – review and editing, Visualization. **Haralampos Petridis:** Conceptualization, Validation, Supervision.

https://doi.org/10.1016/j.prosdent.2024.02.012